

PROBLEMS AND ISSUES IN SOLAR SYSTEM AERONOMIC MODELING

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The comparative approach to planetary aeronomy is becoming increasingly fruitful as new information from various planet atmospheres is assimilated. Various planetary thermospheric observations and modeling over the past 35-years provide a useful platform for addressing similar upper atmosphere processes (thermal, dynamical, chemical) in various planetary settings. Planetary upper atmospheres can be roughly categorized as those imbedded in its own planetary magnetosphere (Earth and Jupiter) and those that are not (Venus, Mars, Titan). This distinction determines the different thermospheric heating mechanisms that generally dominate for magnetic (auroral and Joule heating) and non-magnetic (solar EUV/UV heating) bodies. In addition, other basic features of the structure and dynamics of the Venus, Earth, Mars, Jupiter and Titan thermospheres can be understood by examining the implications of their fundamental planetary parameters (*e.g.* radius, gravity, heliocentric distance, rotation rate).

The present maturity of available Venus and Earth planetary databases (and the promise for Mars) as well as numerical modeling capabilities permit us to compare the thermospheres of Venus, Earth, and Mars using well tested and individually validated three-dimensional (3-D) thermospheric general circulation models (TGCMs). Recently developed Jupiter and Titan TGCMs also reveal unique characteristics of their thermospheric winds and structures that data have yet to confirm. We present sample TGCM simulations that capture the physics of these 5-thermospheres. Clearly, our geocentric perspective when applied to other planet atmospheres is initially helpful. However, investigations must be revised as new planetary data and model simulations combine to challenge our understanding of aeronomic processes in new planetary environments.

Table 1a. Terrestrial Planet Parameters

Parameter	Earth	Venus	Mars
Gravity, cm/s ²	982	888	373
Heliocentric distance AU	1.0	0.72	1.38-1.67
Radius, km	6371	6050	3396
Ω , rad/s	7.3(-5)	3.0(-7)	7.1(-5)
Magnetic dipole moment (wrt Earth)	1.0	$\leq 4.0(-5)$	$\leq 2.5(-5)$
Obliquity, deg	23.5	1-3	25.0

Table 1b. Implications of Parameters

Effect	Earth	Venus	Mars
Scale heights, km	10-50	4-12	8-22
Major EUV heating, km	~200-300	~140-160	120-160
O Abundance (ion peak)	broad	narrow	intermediate
CO ₂ 15- μ m cooling	~40%	~7-20%	~1-4%
Dayside thermostat	≤ 130 km	≤ 160 km	$\leq 125-130$ km
Dayside solar cycle T	conduction	CO ₂ cooling	winds/conduction
Rotational forces	900-1500 K	230-310 K	220-325 K
Cryosphere	important	negligible	important
Auroral/Joule heating	no	yes	no
Seasons	yes	no	yes

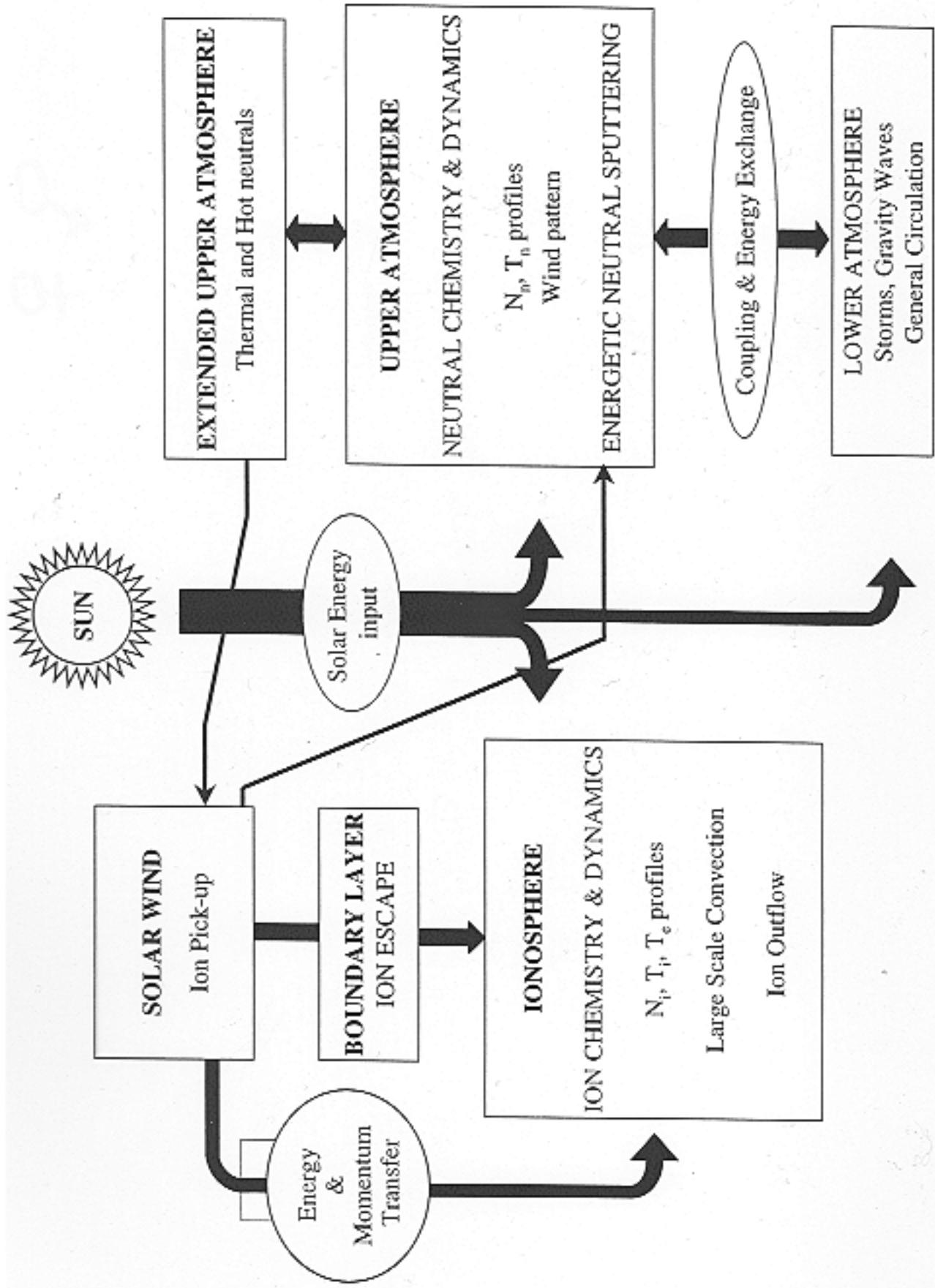
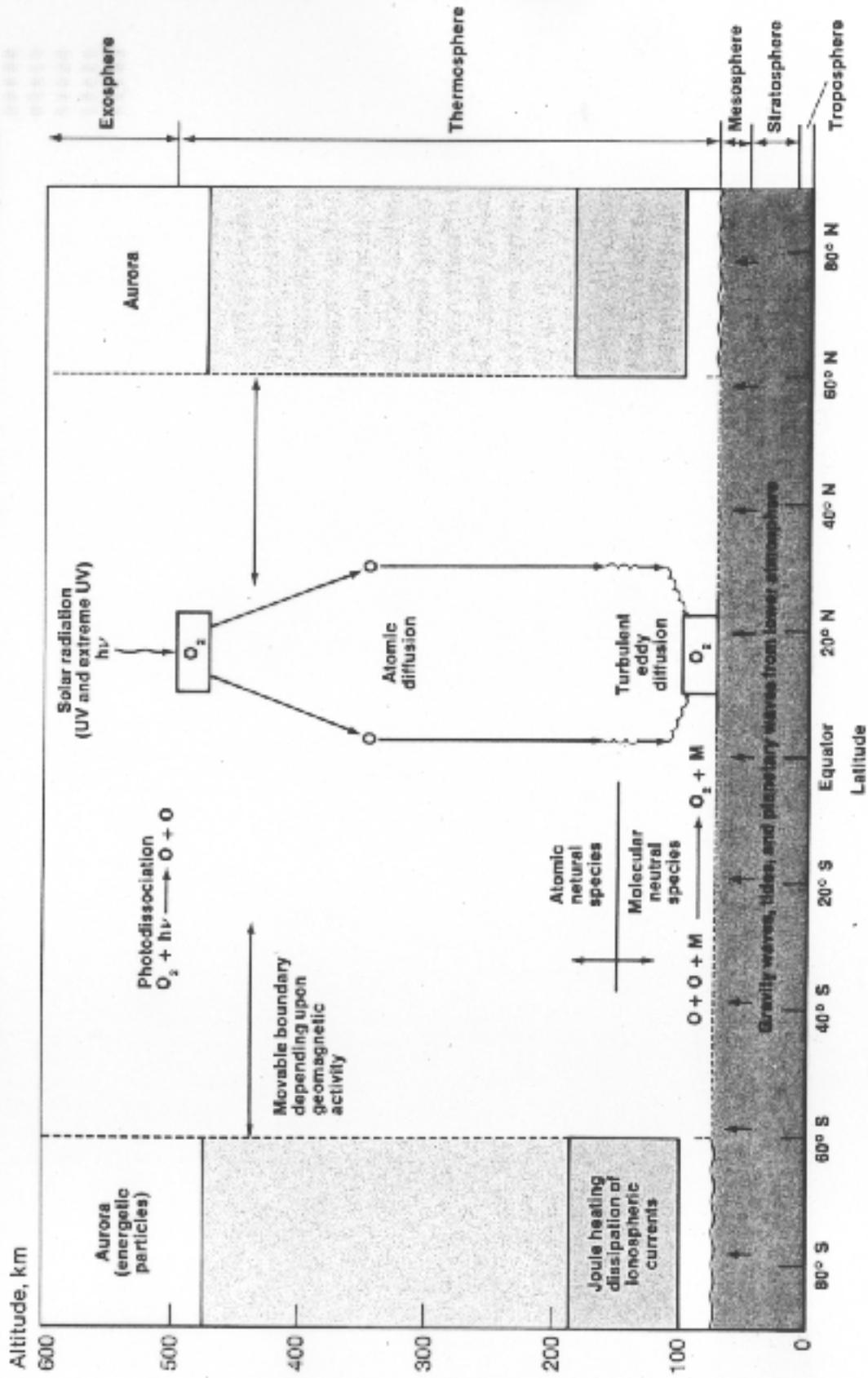
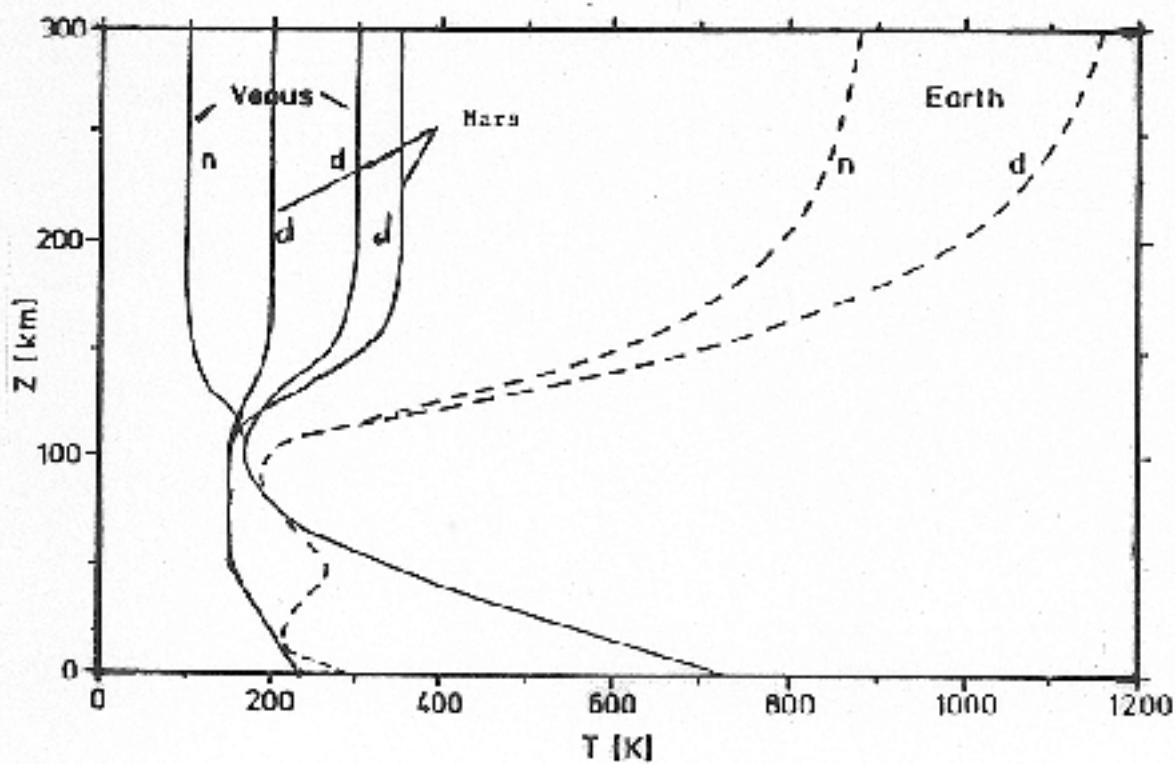
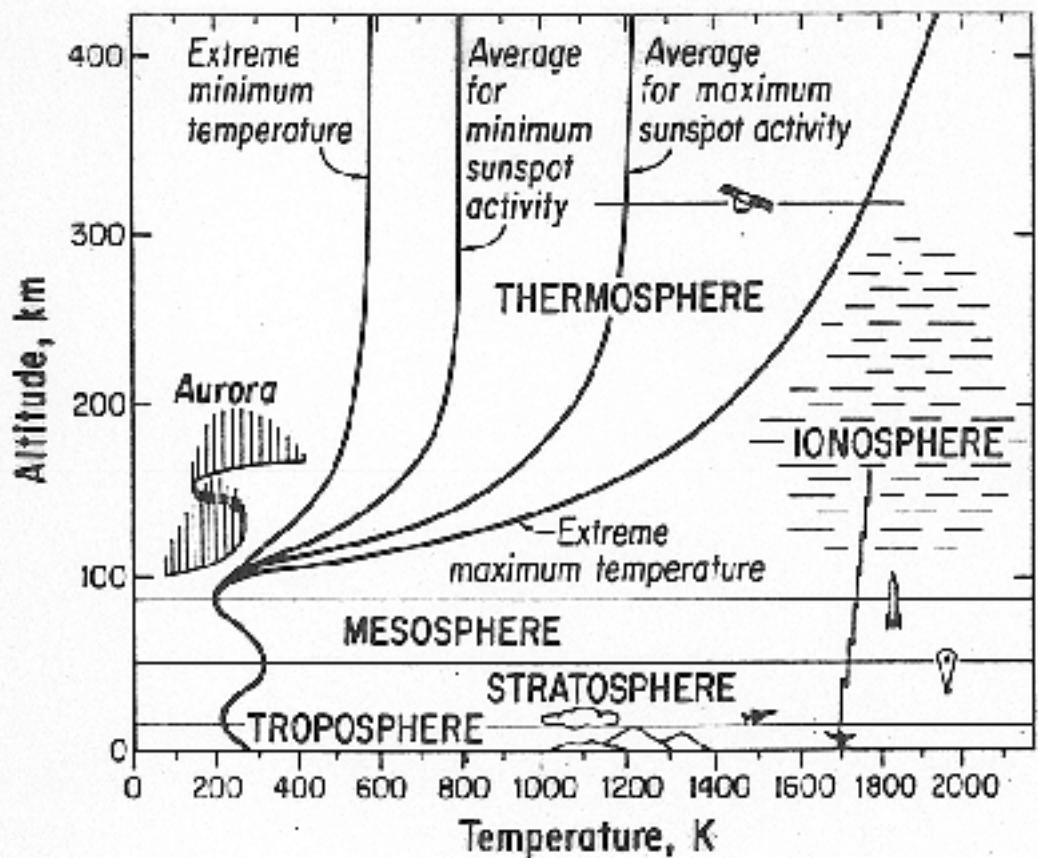


Fig. 1 Mars atmospheric processes illustrated by atmospheric region. The coupling between atmospheric regions is clearly evident.

Solar radiation and auroral processes determine the structure of the thermosphere



The main energy source that governs the structure and dynamics of the thermosphere is the solar extreme ultraviolet and ultraviolet radiation that is absorbed there. An O_2 molecule is dissociated into atomic oxygen by such absorption, and atomic oxygen diffuses downward toward the 100-km region, where it recombines to O_2 by the three-body reaction $O + O + M \rightarrow O_2 + M$. At altitudes above about 150 km, atomic oxygen dominates; below 150 km molecular nitrogen and molecular oxygen dominate. The thermosphere is also strongly perturbed by such auroral processes as aurora particle precipitation and the Joule dissipation of ionospheric currents at high altitudes, as well as by upward propagating tides, gravity waves, and planetary waves from the lower atmosphere.

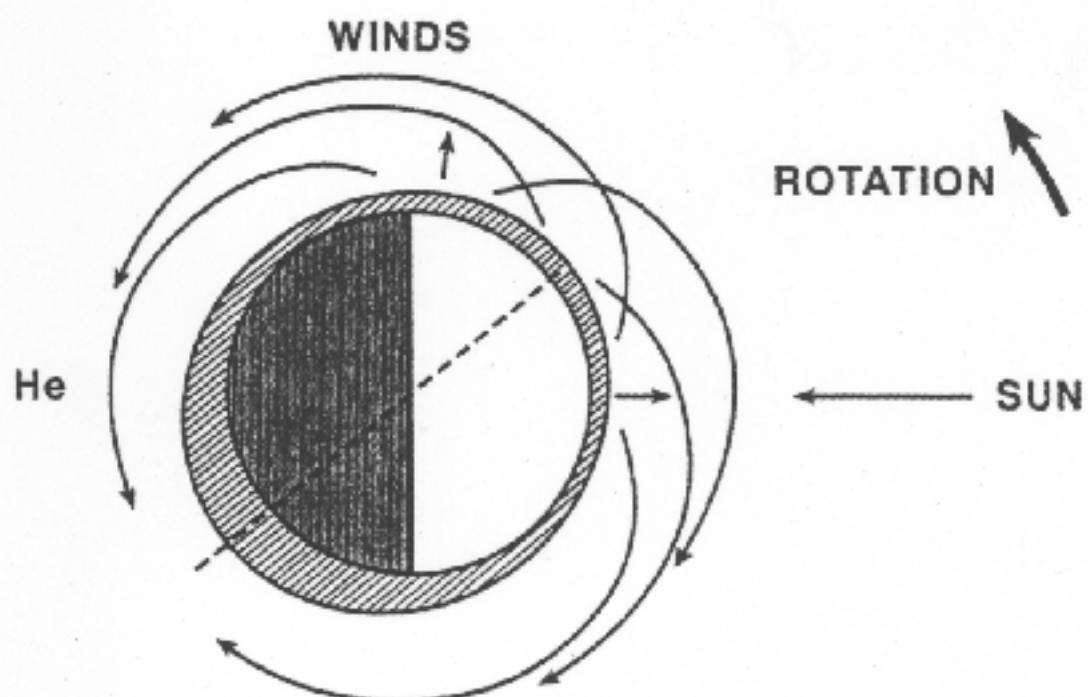
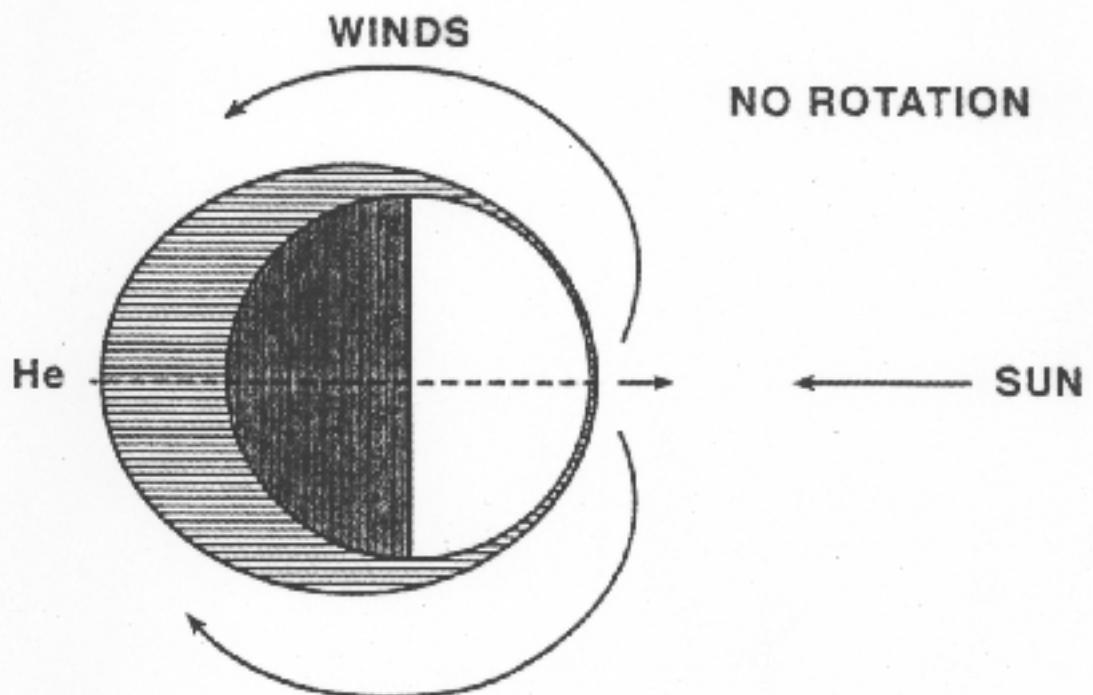


The High Exobase Temperatures of the Giant Planets

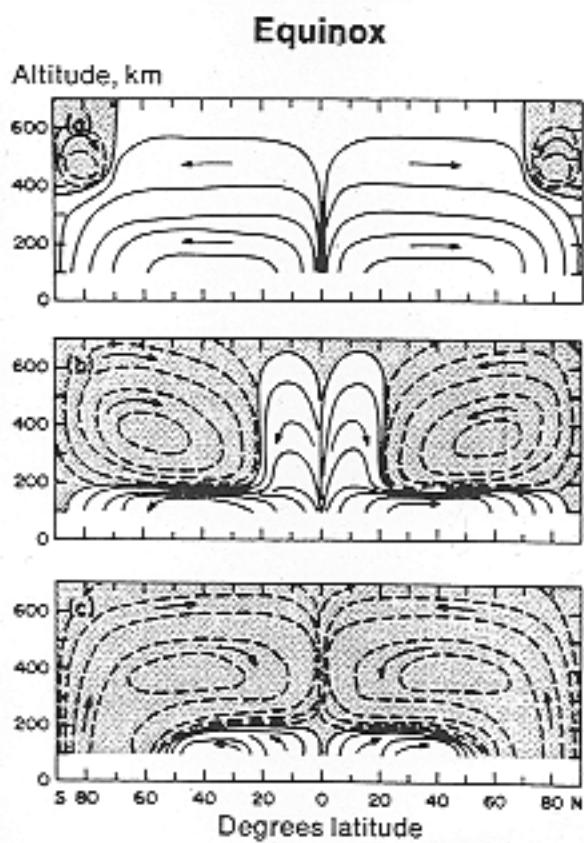
	Heliocentric Distance (AU)	T_{∞} ('K) from Solar UV/EUV	Voyager Inferred T_{∞} ('K)
Jupiter	5.2	195	1000
Saturn	9.5	130	420
Uranus	19.2	113	850 ± 100
Neptune	30.1	141	750 ± 150

Table 1:
GLOBAL ENERGY BUDGETS : POWER IN WATTS
(VENUS, EARTH, MARS, JUPITER)

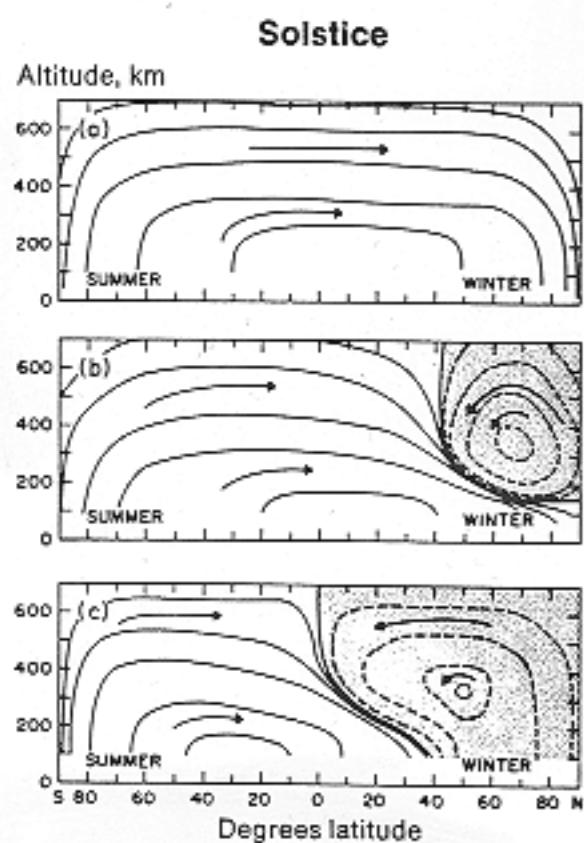
PLANET	P(EUV)	P(Auroral)	P(Joule)	P(Total)
Venus	2-4E+11	—	—	2-4E+11
Earth (Quiet)	2-6E+11	0.13E+11	0.7E+11	2.8-6.8E+11
Earth (Storm)	2-6E+11	3.0E+11	1.0E+12	1.5-2.0E+12
Mars	1.6-3.3E+10	—	—	1.6-3.3E+10
Jupiter (Storm)	8.0E+11	1.0E+14	$\geq 1.0E+14$	$\geq 2.0E+14$



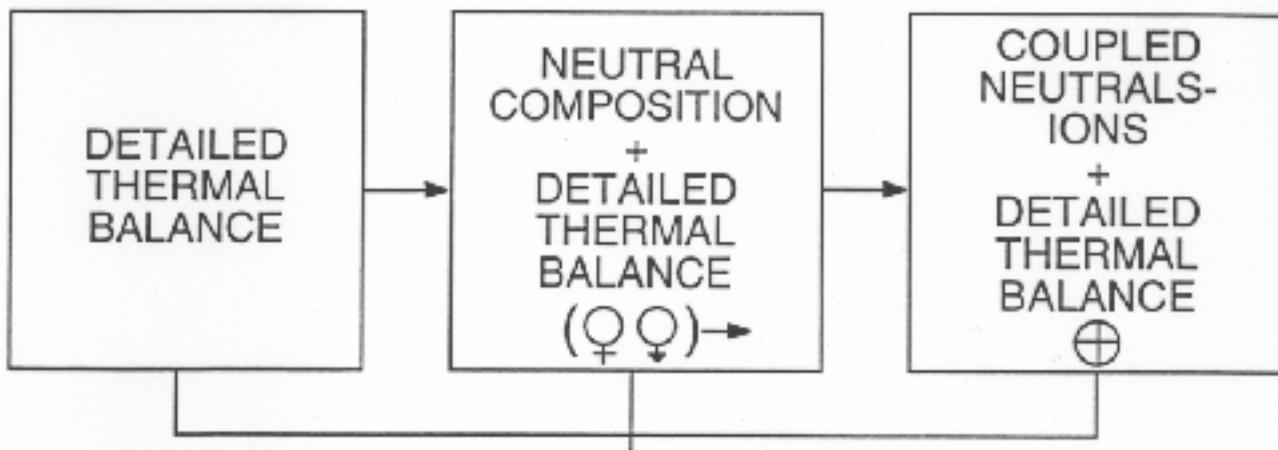
Geomagnetic activity and season strongly influence circulation in the thermosphere



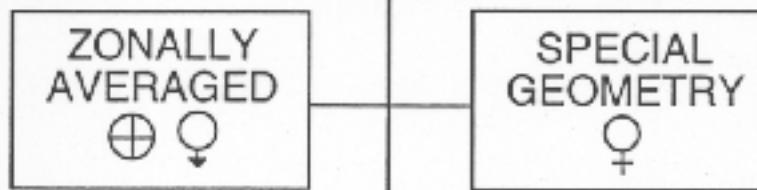
Quiet period
Average auroral activity
Geomagnetic storm



ONE DIMENSIONAL GM MODELS (1D)



SIMPLIFIED DYNAMICAL MODELS (2D)



GLOBAL MODELS (3D)

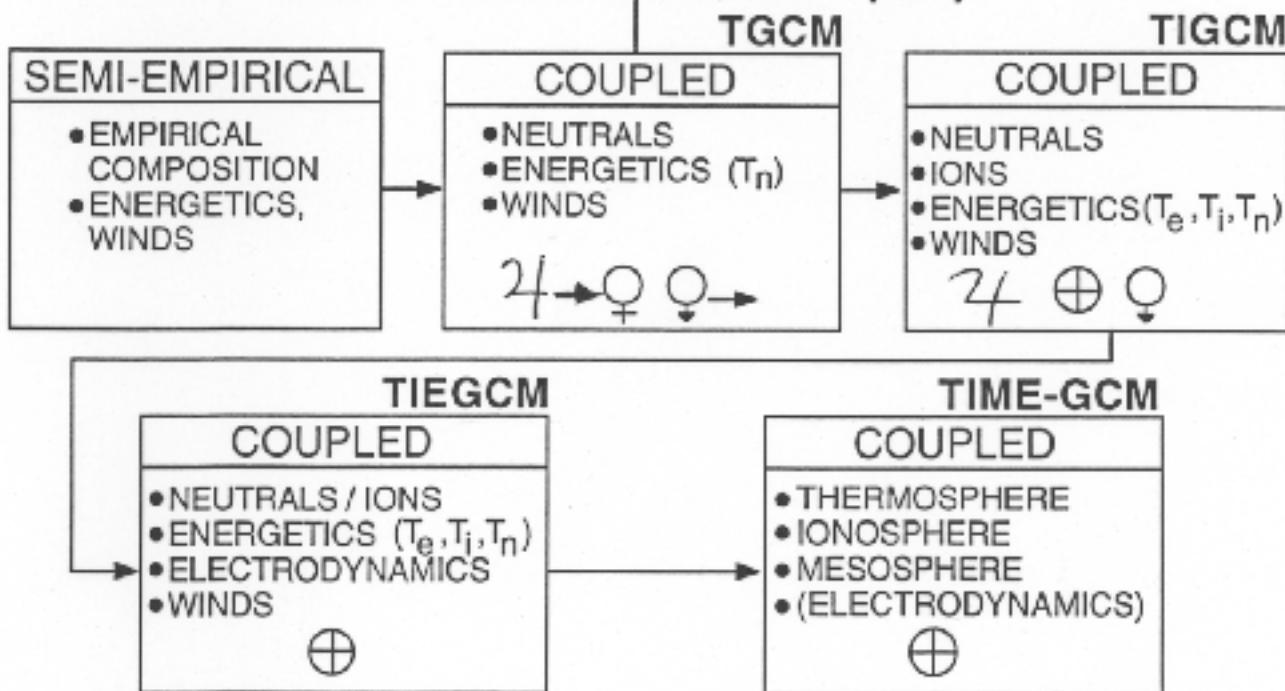
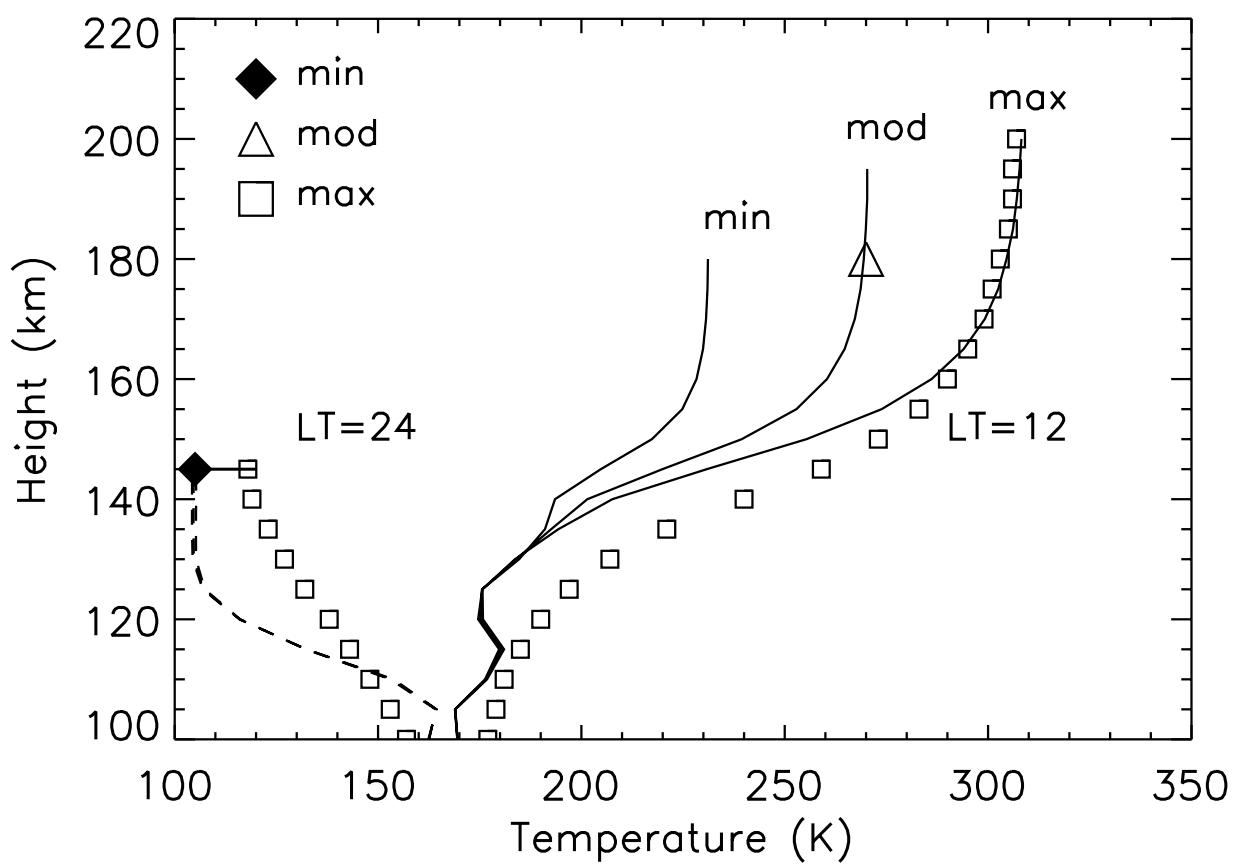


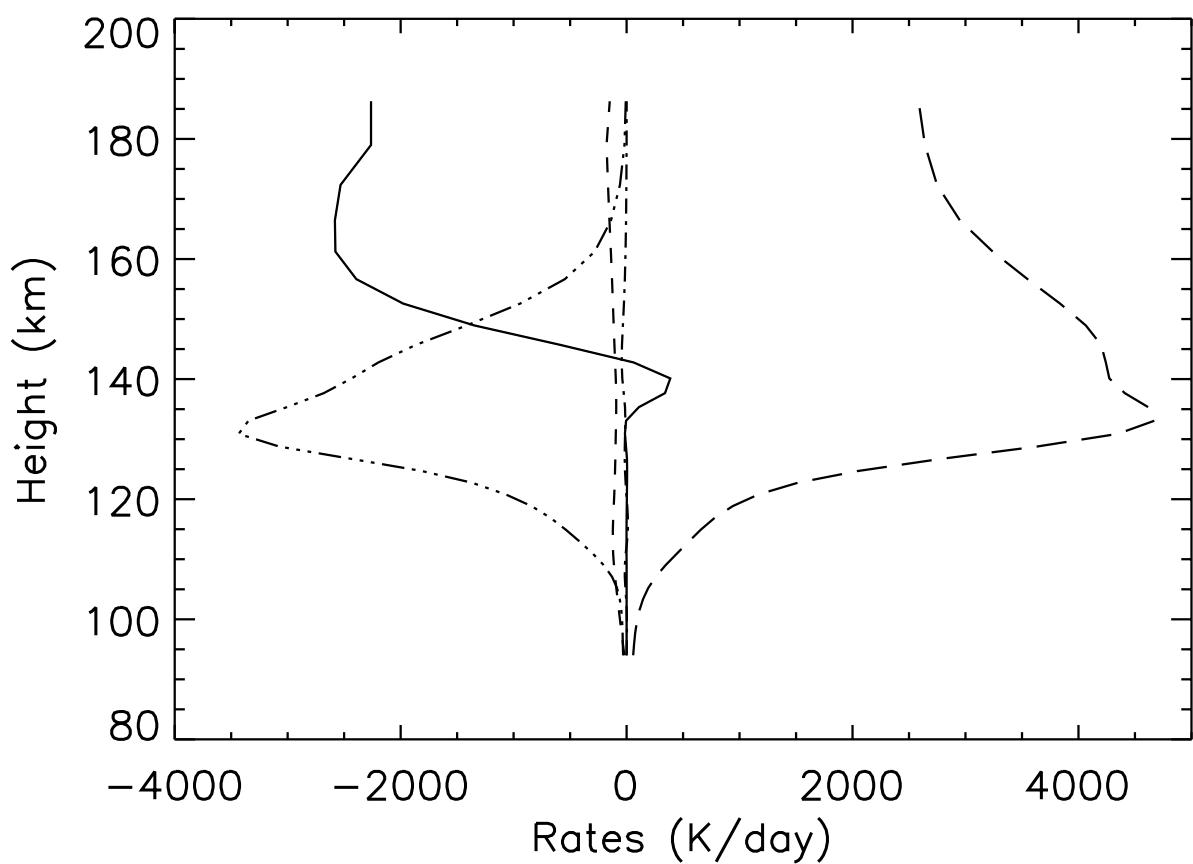
Table 1. NCAR TGCM Input Parameters, Fields, and Computation Domains

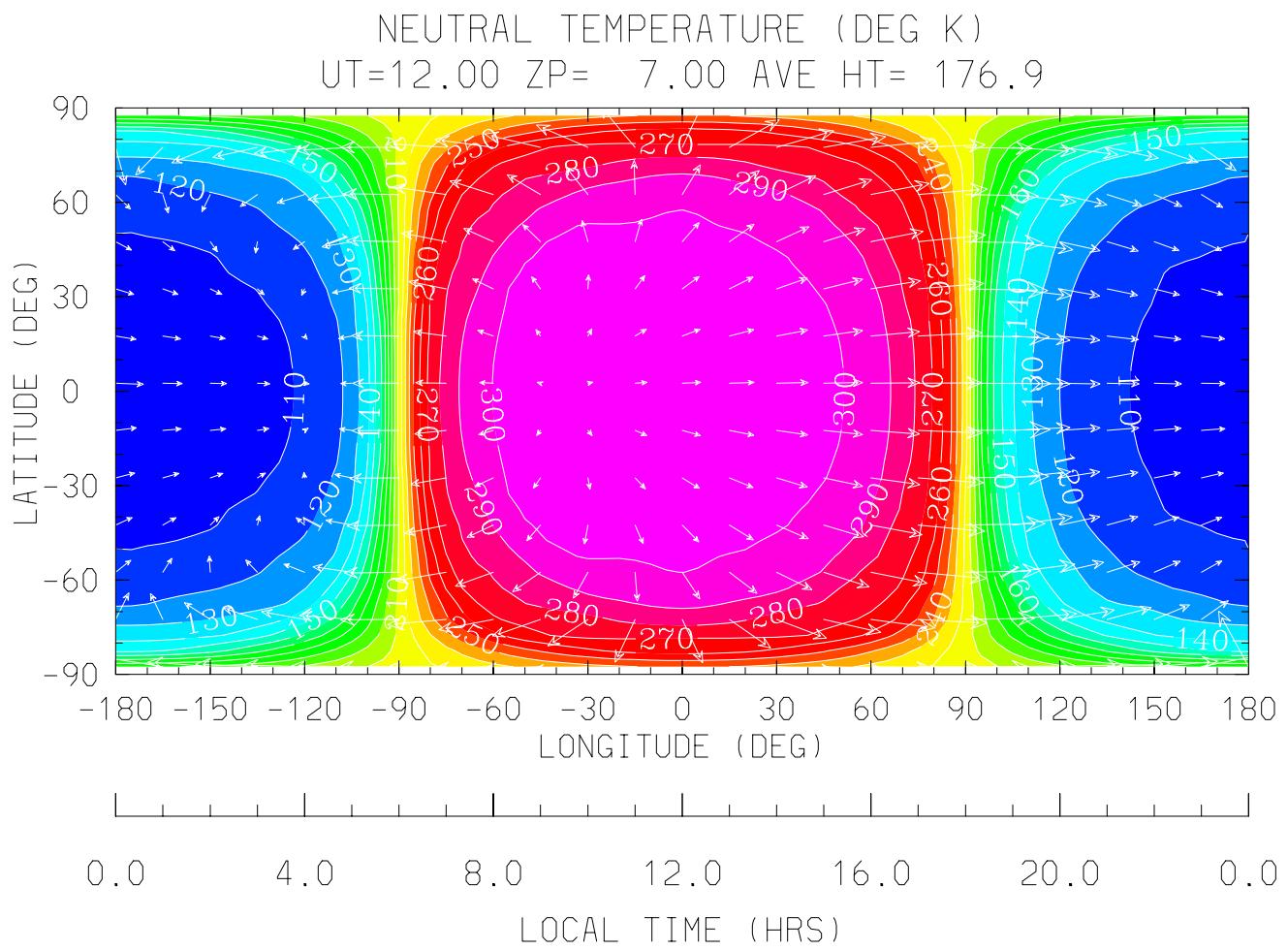
TGCM	Domain -Alt Range -Pres Range Resolution (LatxLon)	Major Species	Minor Species	Ions	Time-Step (secs)	Homopause Kzz (cm ² /sec)	Heating Efficiencies (EUV vs. UV)
VTGCM	94-200 km 11-4.6E-7 Pa 33-levels 5x5 degrees	CO ₂ CO O N ₂	O ₂ He NO N(4S) N(2D)	CO ₂ +	180	1.0E+7 (at 136 km)	EUV = 20% UV=22%
MTGCM	70-300 km 0.13-1.5E-8 Pa 33-levels 5x5 degrees	CO ₂ CO O N ₂	O ₂ He Ar NO N(4S)	CO ₂ +	150	1-2.0E+7 (at 125 km)	EUV= 22% UV=22%
TIE-GCM	95-800 km 0.06-4.6E-8 Pa 29-levels 5x5 degrees	N ₂ O ₂ O	He Ar NO N(4S) N(2D)	O+ (DYN) O ₂ +	300	1.6E+6 (at 100 km)	EUV=30-40% UV=30-40% Chem ≤60% < 200 km)
JTGCM	250-3000 km 2.0-1.1E-8 Pa 39-levels 5x5 degrees	H ₂ He H	CH ₄ C ₂ H ₂ C ₂ H ₆ H ₂ vib(1-4)	H+ (DYN) H ₂ +	30	2.0E+6 (at 0.45 Pa)	Auroral Heat DISC : 110 ergs/cm ² DIFF. : 0.5 ergs/cm ²

COMMON TGCM INPUTS FOR SEASONAL - SOLAR CYCLE CASES

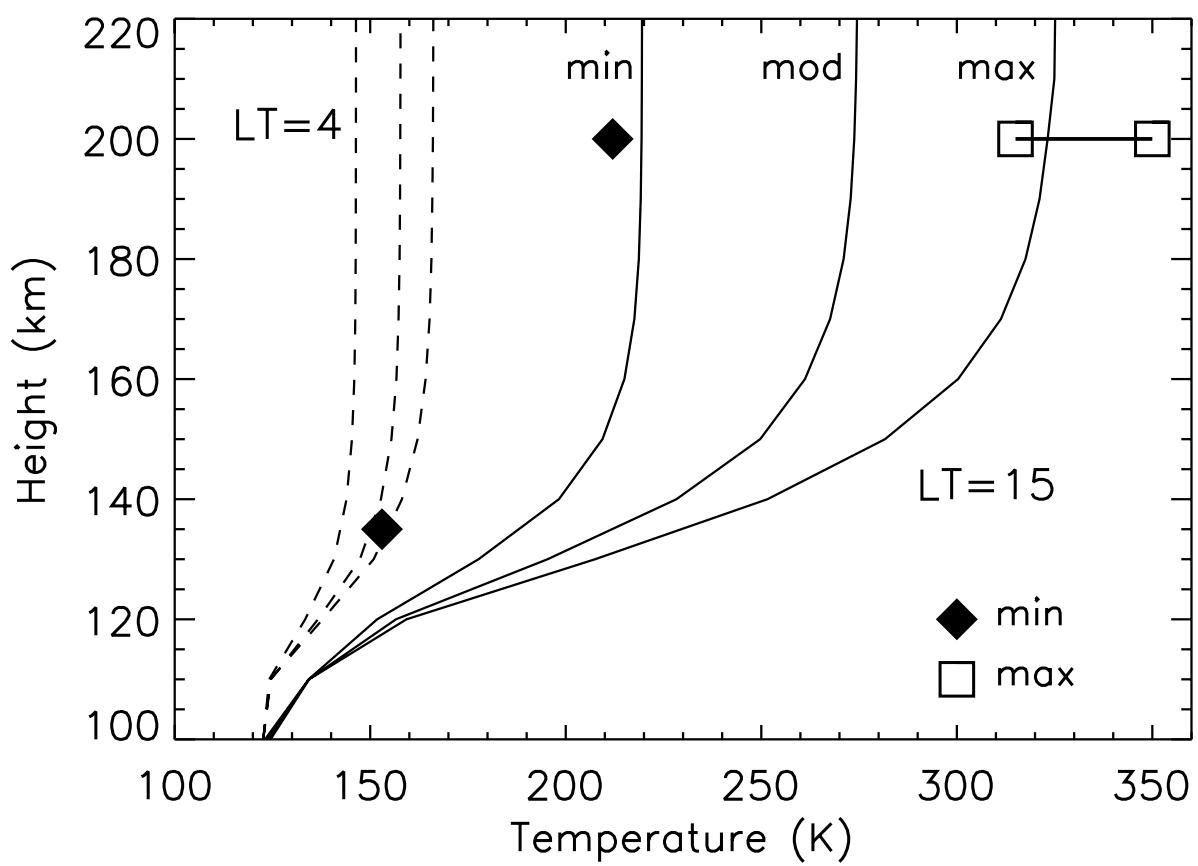
- F10.7-cm indices used to specify standard EUV-UV fluxes
 - F10.7 = 70, 130, 200 for SMIN, SMED, SMAX cases
 - Hinteregger contrast ratio method (Solomon subroutine)
 - Fluxes from 2.0 to 200.0 nm
 - Eccentricity variations ($\pm 3\%$ Earth; $\pm 20\%$ Mars)
- Heating efficiencies specified based upon off-line calculations
 - VTGCM : EUV (20%), UV(22%)
 - MTGCM : EUV (22%), UV(22%)
 - TIEGCM : EUV (30-40% over 200-300 km; up to 60% below 200 km)
 - TIEGCM : UV(30-40%)
- Common O-CO₂ relaxation rate
 - $3.0 \times 10^{-12} \text{ cm}^3/\text{sec}$ at 300K
 - Weak temperature dependence (square root of T)
- Eddy diffusion/conduction from standard formulations. Kmax :
 - VTGCM : $1.0 \times 10^7 \text{ cm}^2/\text{sec}$ at 135 km
 - MTGCM : $1.0-1.5 \times 10^7 \text{ cm}^2/\text{sec}$ at 125 km
 - TIEGCM : $1.6 \times 10^6 \text{ cm}^2/\text{sec}$ near 100 km
- Low auroral activity parameters for Earth TIEGCM
 - Cross tail potential of 45KV
 - Integrated global power input of 16.0 GW
- Tidal parameters specified at the lower boundaries
 - MTGCM : semi-diurnal amplitudes and phases from NASA AMES MGCM
 - TIEGCM : diurnal & semi-diurnal amplitudes and phases from Forbes seasonal climatology

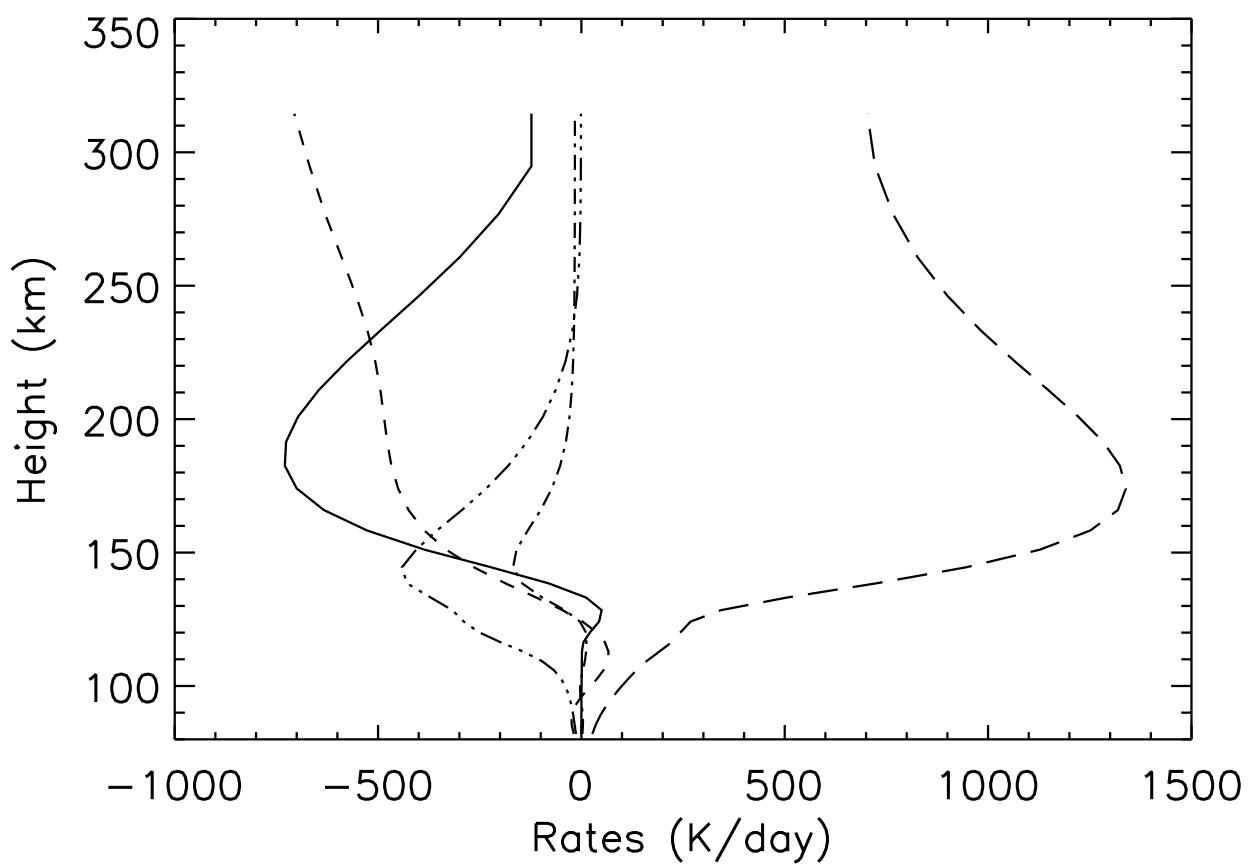


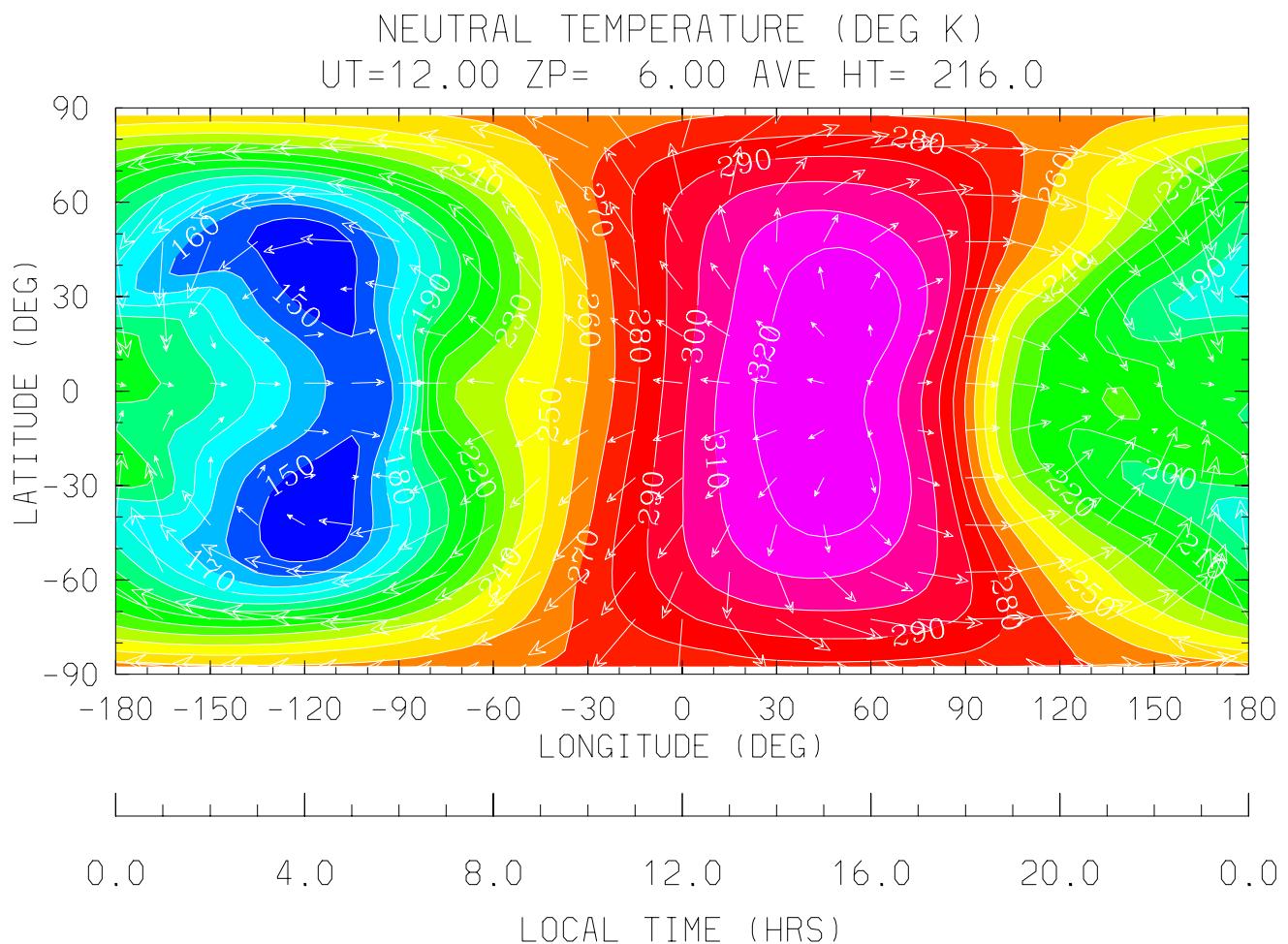




0.263E+03
 $\overrightarrow{UN+VN}$

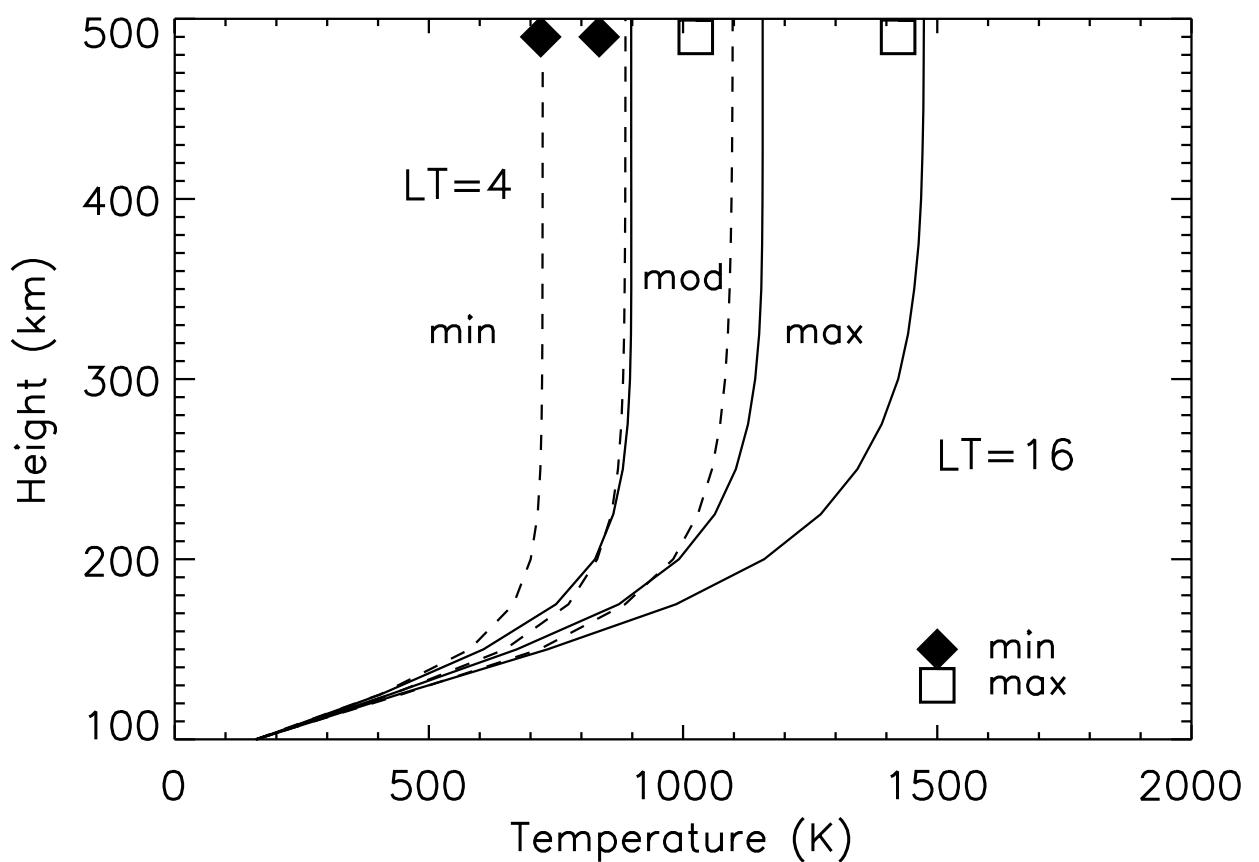


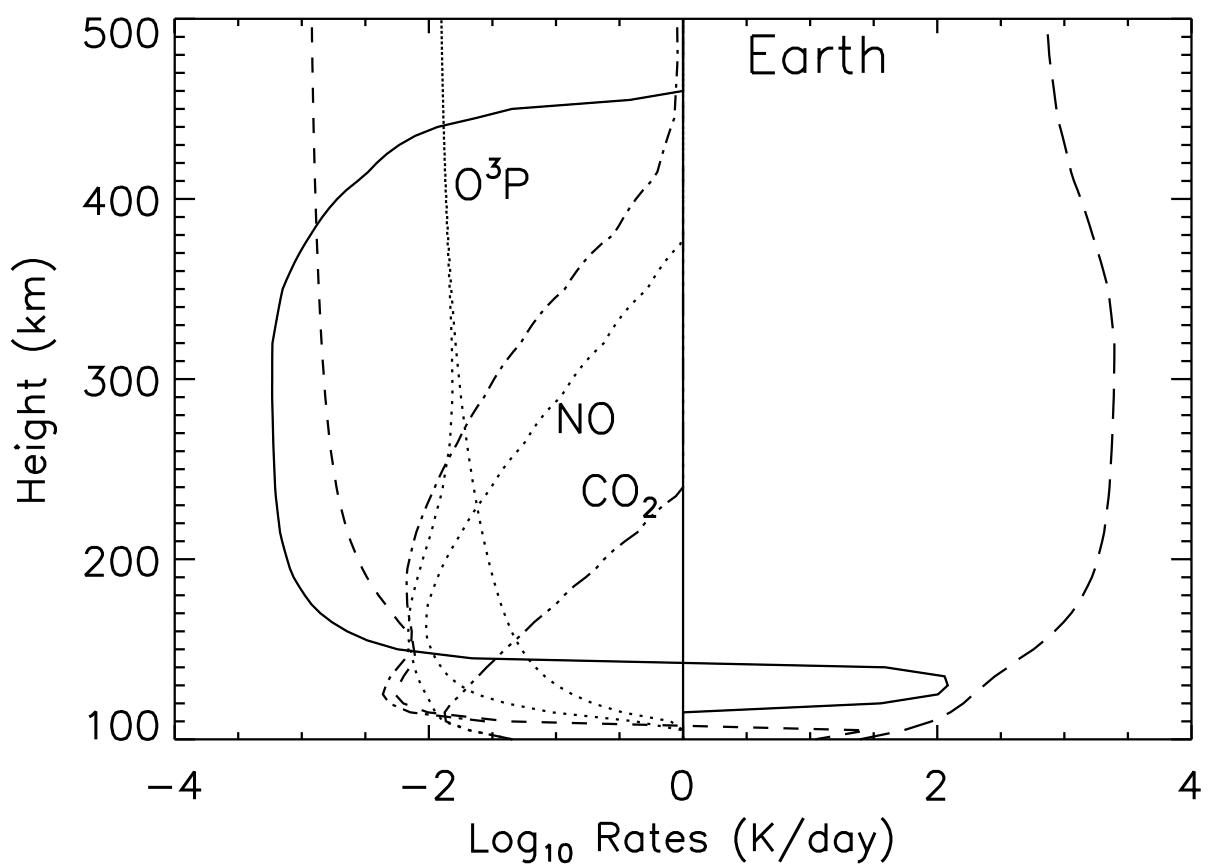


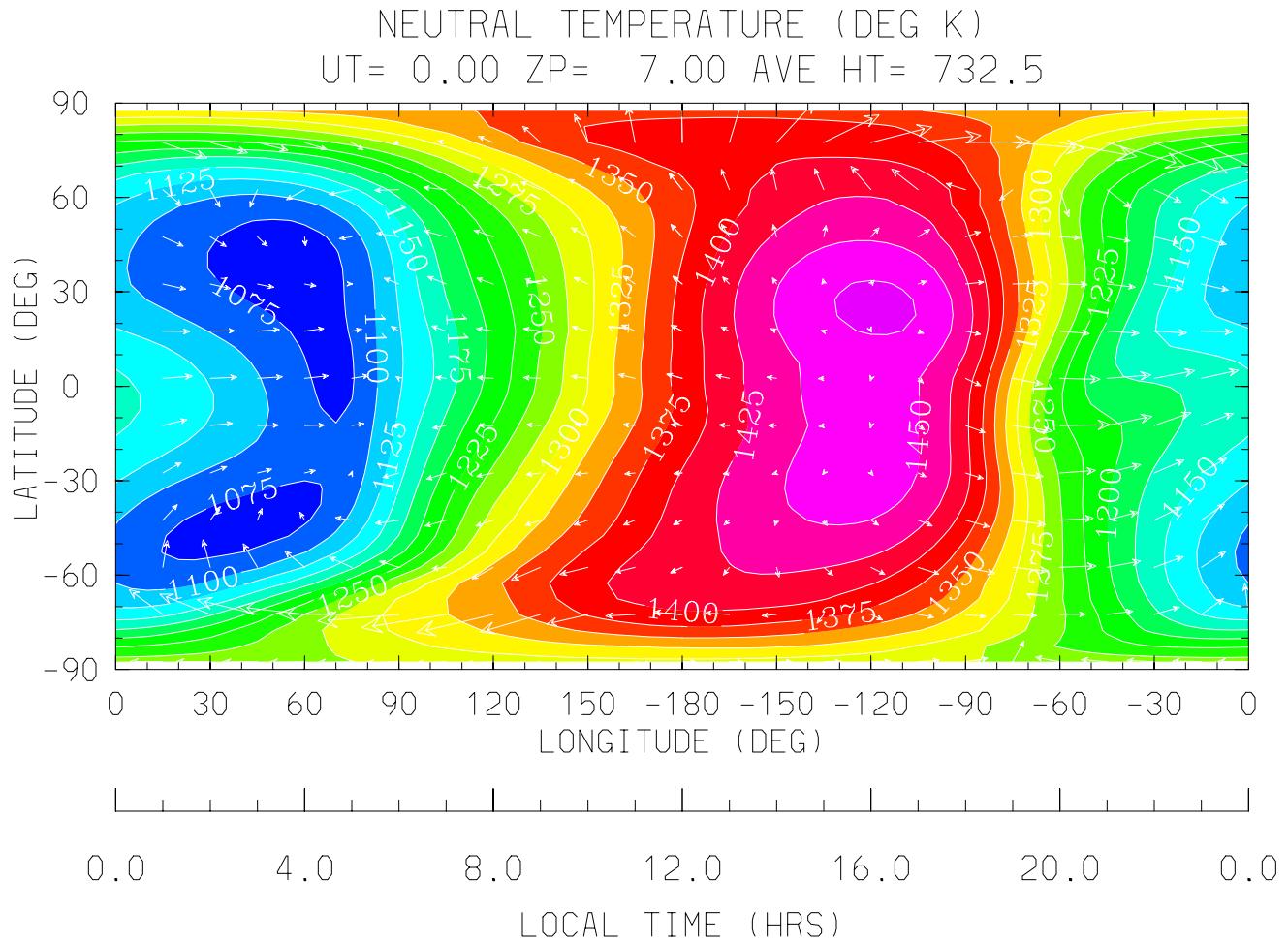


0.305E+03

$\xrightarrow{\hspace{1cm}}$

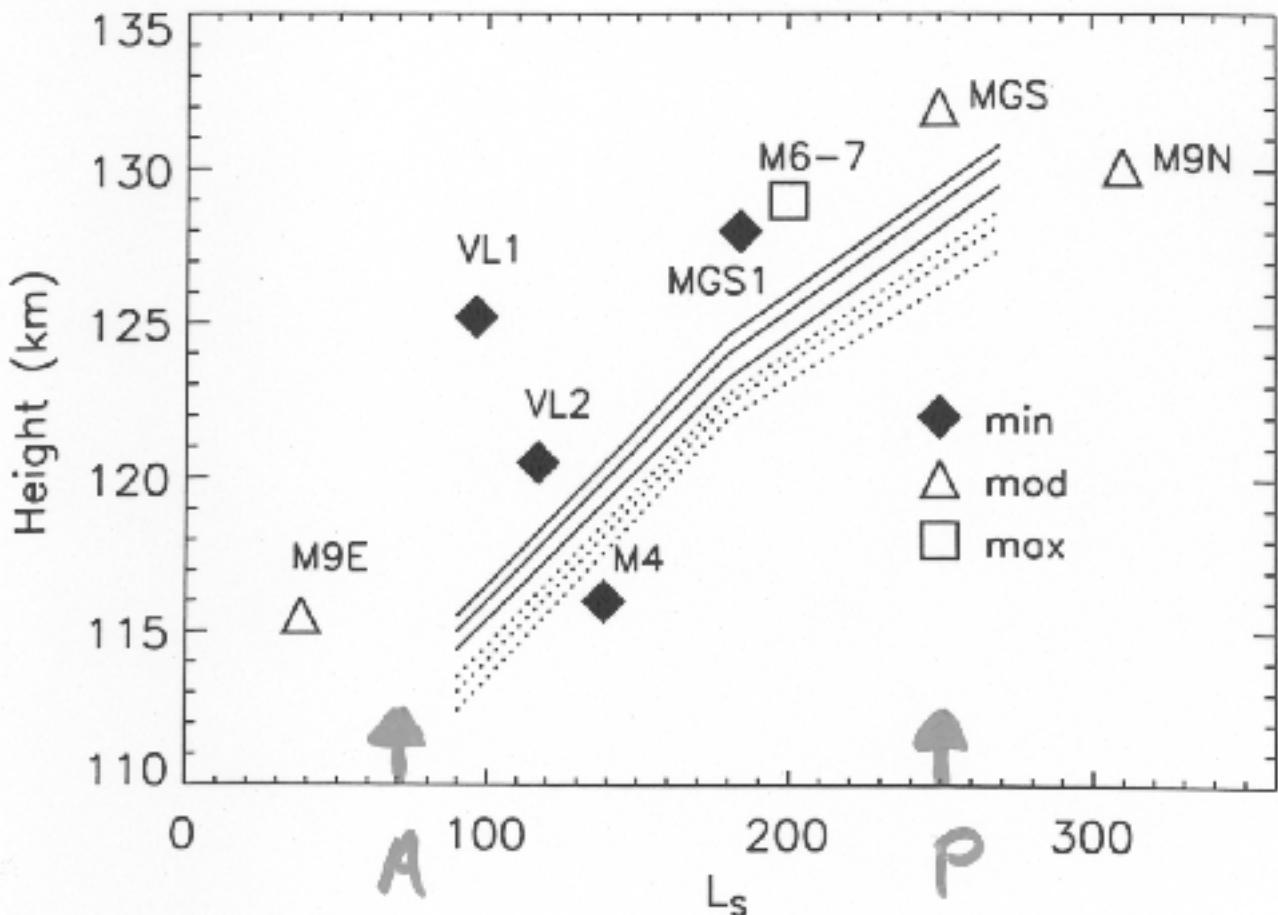






0.477E+03
 $\overrightarrow{UN+VN}$

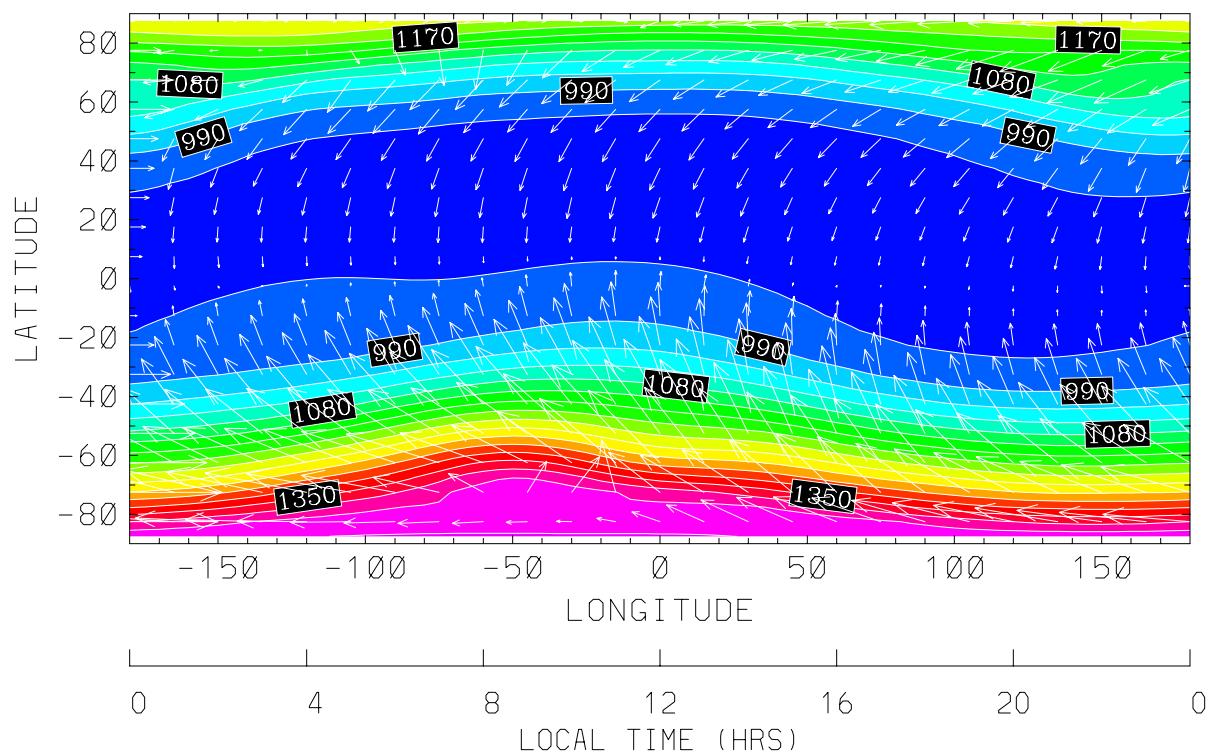
MARS THERMOSPHERE 1.26-NBAR HEIGHTS
VERSUS SOLAR CYCLE, SEASON, AND SZA
(SZA = 0 and 60°)



- Seasonal “inflation and contraction” yields ~ 15 km variation.
- Systematic height offset (2-4 km) due to low level dust ($\tau=0.3$).
- Low SZA effects ($0-60^\circ$) are small (1-2 km).
- Episodic height offsets (8-20 km) due to dust storm events.

JTGCM NEUTRAL TEMPERATURE (DEG K)

ZP= 17.0 UT=-12.00



MIN 935.9, MAX 1445.1, INTERVAL 30

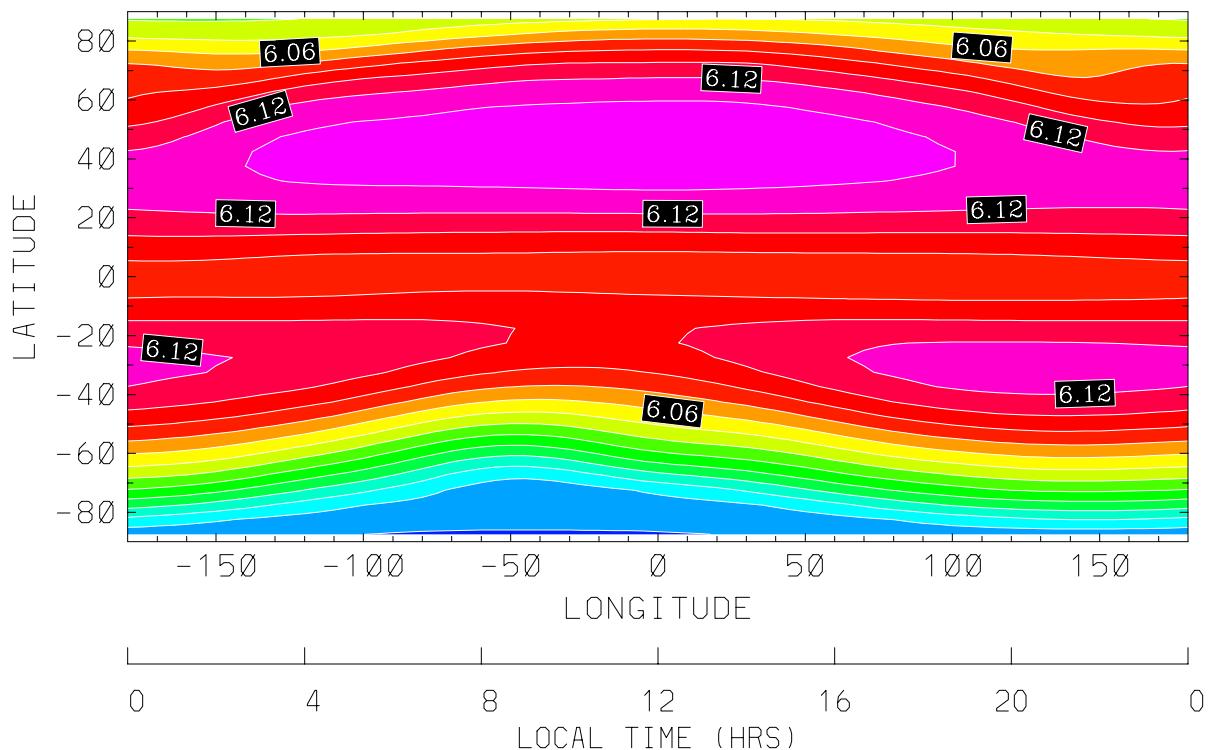
HISTORY=/BOUGHER/SWBJ00/JP178

CENTER OF PROJECTION = 0.0, 0.0

970 M/S
→

LOG10 JTGC M H NUMBER DENSITY (CM⁻³)

ZP= 17.0 UT=-12.00

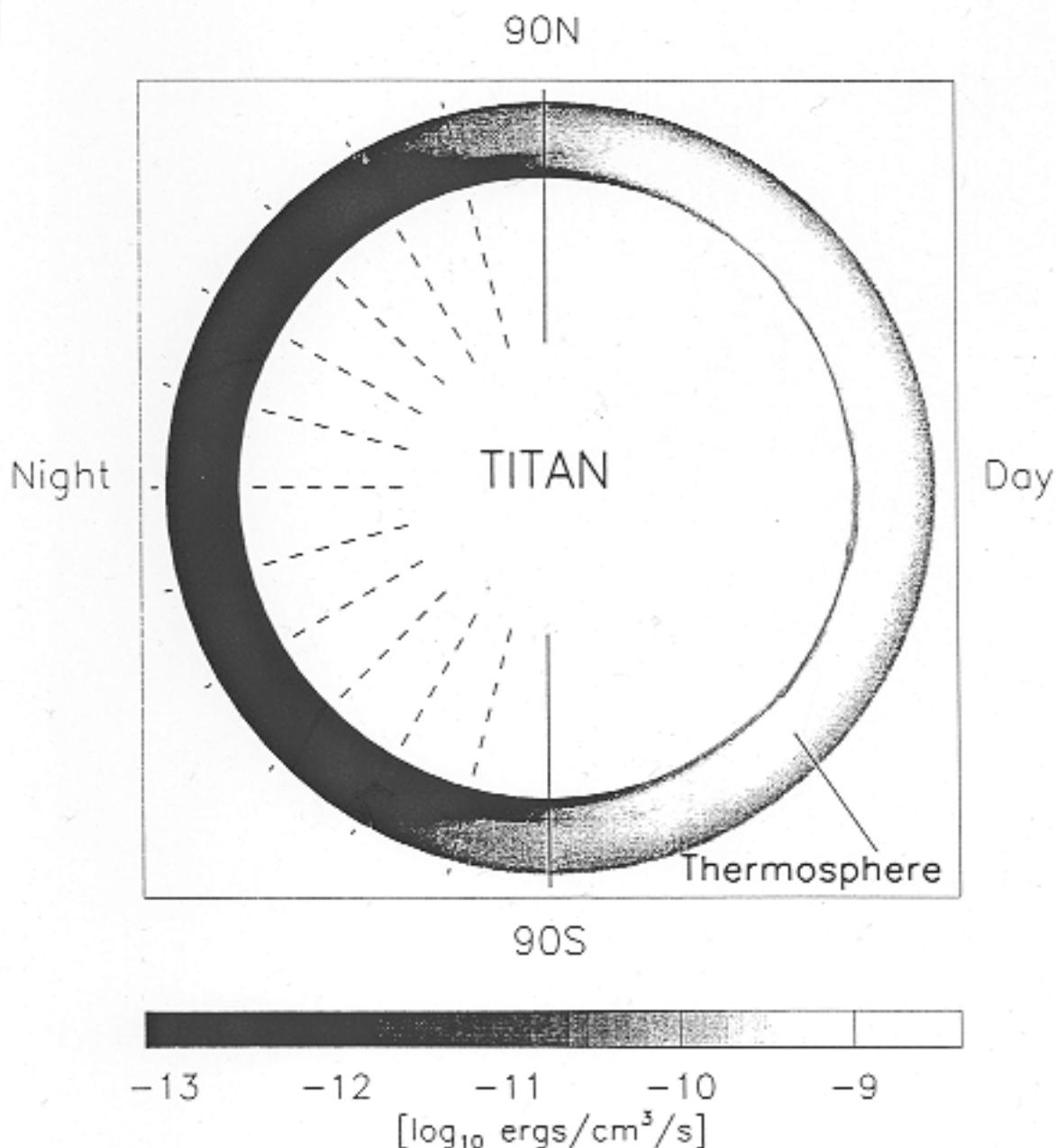


MIN 5.9380, MAX 6.1458, INTERVAL .015

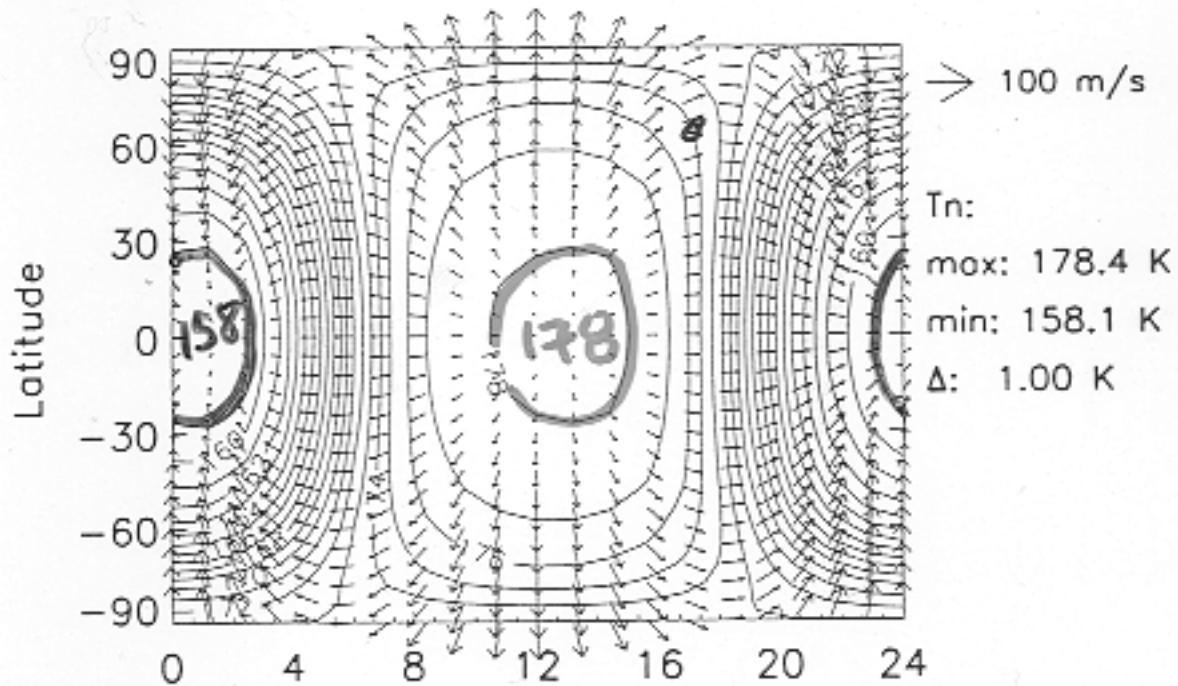
HISTORY=/BOUGHER/SWBJ00/JP178

CENTER OF PROJECTION = 0.0, 0.0

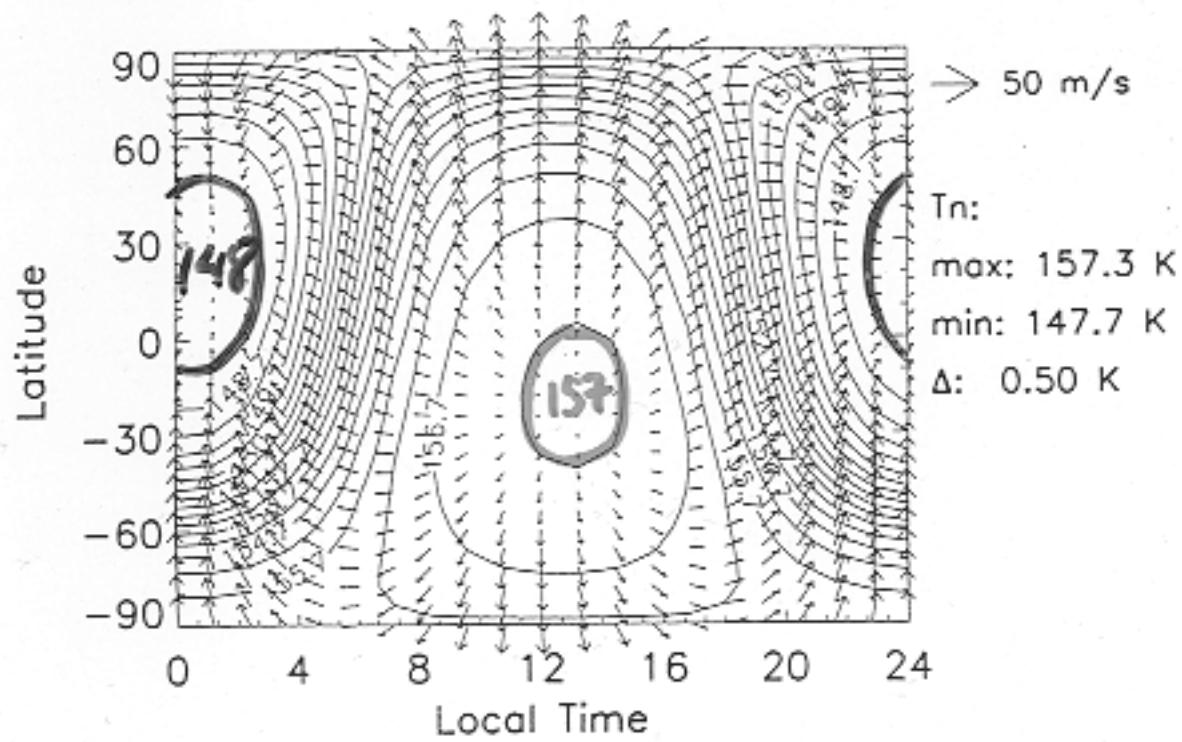
Parameter	Titan	Triton
Radius	2575 km	1353 km
Sun distance	9.5 AU	30.5 AU
Pressure range	0.1 μ bar - 1 pbar	1 μ bar - 0.01 pbar
Height range	600 - ca. 1400 km	10 - ca. 420 km
Gravity at bottom	0.89 ms ⁻²	0.75 ms ⁻²
Rotation rate (duration of day) and orientation	4.6×10^{-6} s ⁻¹ (15.8 days)	-1.3×10^{-5} s ⁻¹ (5.6 days)
Max. subsolar latitude	$\lambda_{max} = 24^\circ$	$\lambda_{max} = 50^\circ$
Mixing ratios	<i>Yung et al. [1984]</i>	99.99 % N ₂ ; 0.01 % CH ₄



Titan, Equinox (solar max)



Titan, Solstice (solar min)



ISSUES IN SOLAR SYSTEM AERONOMIC MODELING :

- Common modeling framework (TGCM). Evaluation of assumptions inherent in energy, momentum, and continuity-diffusion equations (Titan).
- Assessment of role of fundamental parameters in modifying common processes in different planetary environments. First order comparisons :
 - Magnetic versus non-magnetic planets : heating implications
 - Rotation rate : global dynamical implications
 - Gravity : implications for scale heights and atmospheric extent
- Components of 1-D heat budget and vertical placement of heating and cooling terms. IR cooling agent and its relative importance.
- Simplified (yet representative) ion-neutral chemistry for 3-D models
- Role of dynamics in modifying global structure (temps. and densities)
- Major forcings and their importance for thermal/wind structure :
 - Solar EUV/UV/IR drivers : Venus and Mars
 - Solar EUV/UV plus auroral/Joule/magnetospheric drivers : Earth
 - Largely auroral/Joule/magnetospheric drivers : Jupiter
 - Solar EUV/UV plus Saturn magnetospheric? drivers : Titan
- Time variable behavior of forcings
 - Eccentricity and dust storm events : Mars
 - Auroral activity and magnetospheric convection : Earth and Jupiter
 - Upward propagating gravity waves and tides : all 5-bodies